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Potential Increased Production of Automotive Diesel Fuels

M. W. Kellogg Co, Houston, Tex Refinery Process Div

Prepared for

Environmental Protection Agency, Ann Arbor, Mich Div of Control Systems

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TASK 17 FINAL REPORT

POTENTIAL INCREASED PRODUCTION OF AUTOMOTIVE DIESEL FUELS

Submitted to

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF AIR PROGRAMS

DIVISION OF CONTROL SYSTEMS

Contract No. CPA 70-68

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Automotive diesel engines are more efficient than automotive gasoline engines and thus deliver more power per unit fuel consumption. The diesel engines also are less polluting since their exhaust gases are free from lead contamination and contain less nitrogen oxides (NO_x) than do the gases from gasoline engines. It may be possible, therefore, to significantly reduce automobile pollutants by using diesel engines rather than gasoline engines in the future. The purpose of this study is to estimate the potential production of automotive diesel fuels in the United States since widespread adoption of diesel engines to replace gasoline engines would greatly increase the demand for diesel fuels. The effect of maximizing diesel fuel production on the refinery product slate is also needed since shortages in other areas could develop.

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by

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Potential Increased Production of Automotive Diesel Fuels

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I. INTRODUCTION

This report covers work which was performed under Contract No. CPA 70-68, Environmental Protection Agency, Office of Air Programs, Task No. 17.

Automotive Diesel engines are more efficient than automotive gasoline engines and thus deliver more power per unit fuel consumption. The Diesel engines also are less polluting since their exhaust gases are free from lead contamination and contain less nitrogen oxides (NO_x) than do the gases from gasoline engines. It may be possible, therefore, to significantly reduce automobile pollutants by using Diesel engines rather than gasoline engines in the future. The purpose of this study is to estimate the potential production of automotive Diesel fuels in the United States since widespread adoption of Diesel engines to replace gasoline engines would greatly increase the demand for Diesel fuels. The effect of maximizing Diesel fuel production on the refinery product slate is also needed since shortages in other areas could develop.

It is assumed for this study that the future automotive Diesel fuels would have the same specifications as the present Grade 1-D kerosine type Diesel Fuel and the present Grade 2-D Diesel fuel.

II. Summary

The potential production of automotive Diesel fuels is presented herein for four hypothetical refining situations:

Case 1. A refinery which yields about the same product distribution of total gasolines, mid-distillates, and residual fuel oils as the 1971 U.S. demand.

Case 2. Same refinery as in Case 1 except the catalytic cracking unit yields are at lower conversion to increase the production of mid-distillates.

Case 3. Refinery which features hydrocracker instead of catalytic cracker to further increase production of mid-distillates.

Case 4. Refinery which features hydrocracker and delayed coker for the maximum production of mid-distillates. No residual fuels are produced.

The term "mid-distillates" refers to the distillation boiling range which comprises the kerosines, aviation jet fuel, automotive Diesel fuels and No. 2 fuel oil.

Based on 5,000 million barrels of crude annual demand in the U.S. in 1978, the potential production of automotive Diesel fuels would be as follows:

	Annual Production of Automotive Diesel Fuel, Million Barrels
Case 1	130
Case 2	540
Case 3	950
Case 4	1,610

The above production of automotive Diesel fuels would be in excess of fulfilling the projected 1978 demand for the other distillate products.

III. Discussion

A. General Refinery Situations

No two crude oils or two refineries are the same. Further, no two refineries will produce and have the same product demand. Depending upon the crude properties and refinery process capabilities, different refineries are geared to the following categories or combinations thereof:

- Productions of gasolines, mid-distillates, and residual oil.
- Petrochemical production.
- Lubricant production.
- Asphalt production.
- Production of synthetic natural gas (SNG) and residual fuel oil.

Figure 1 shows the distillations for three different crude oils which are widely different.

In crude topping and vacuum operations, crude oils can be distilled into fractions with true boiling cut points approximately as follows:

- Butanes and lighter components to gas recovery.
- Pentanes to 200°F light gasoline for blending to gasoline or isomerization of the pentanes and hexanes to upgrade the octane number.
- 200° – 350°F Naphtha for reformer feedstock to upgrade the octane number or produce aromatics.
- 350° – 500°F Kerosine for production of aviation jet turbine fuel and kerosine or for blending to Diesel fuel or No. 2 fuel oil.
- 600° – 800°F Gas oil for feedstock to catalytic cracking, thermal cracking, or hydrocracking.
- Heavier than 1,000°F residuum for blending to asphalt or No. 6 fuel oil or produced as feedstock for visbreaking, delayed coking, fluid coking, or solvent deasphalting.

Typical ASTM distillations of refined products to sales are shown in Figure 2. Gasolines distill in the range of 80°F to 400°F, kerosine and jet fuel (kerosine type) distill in the range of 340°F to 530°F, and Diesel fuel and No. 2 fuel oil distill in the range of 350°F to 675°F.

FIGURE 1.4

TYPICAL CRUDE OILS
TRUE BOILING DISTILLATIONS

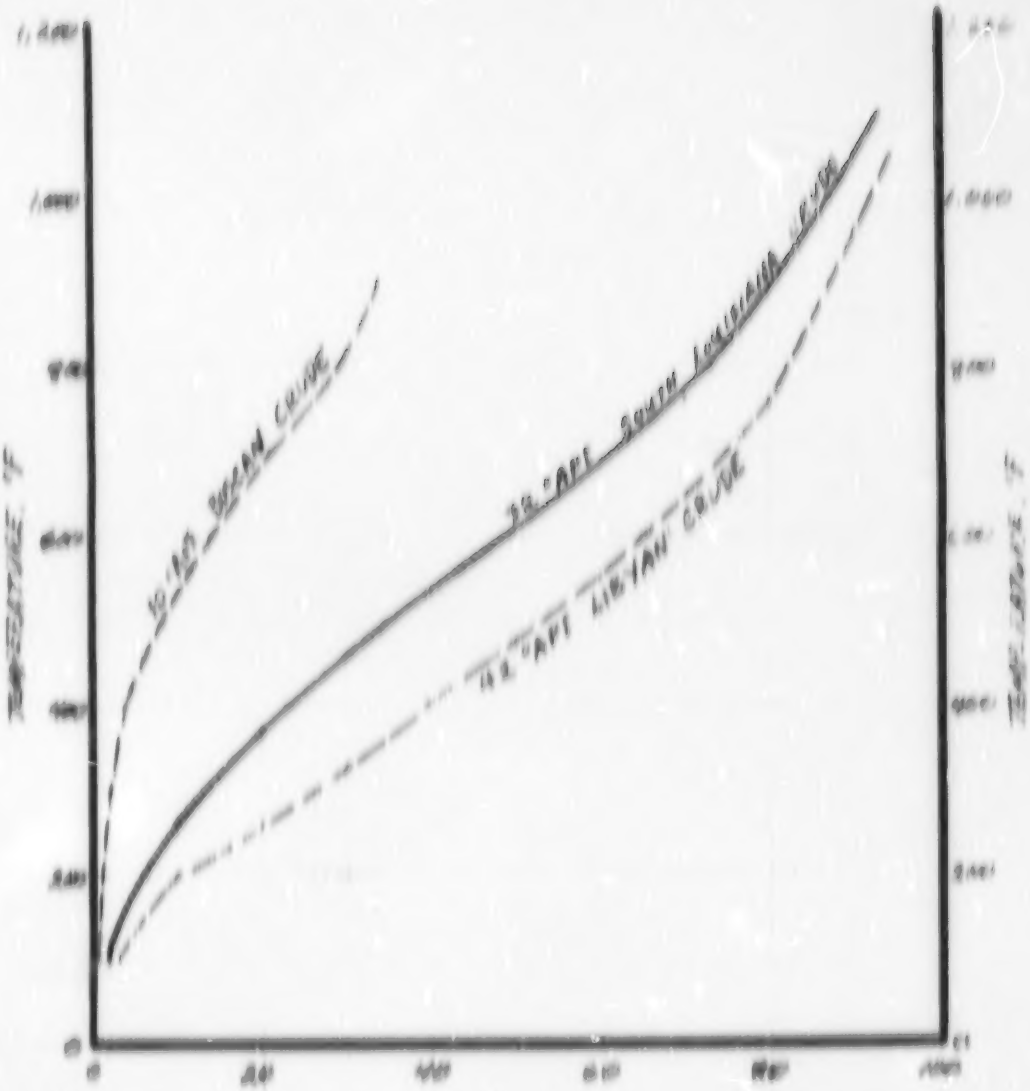
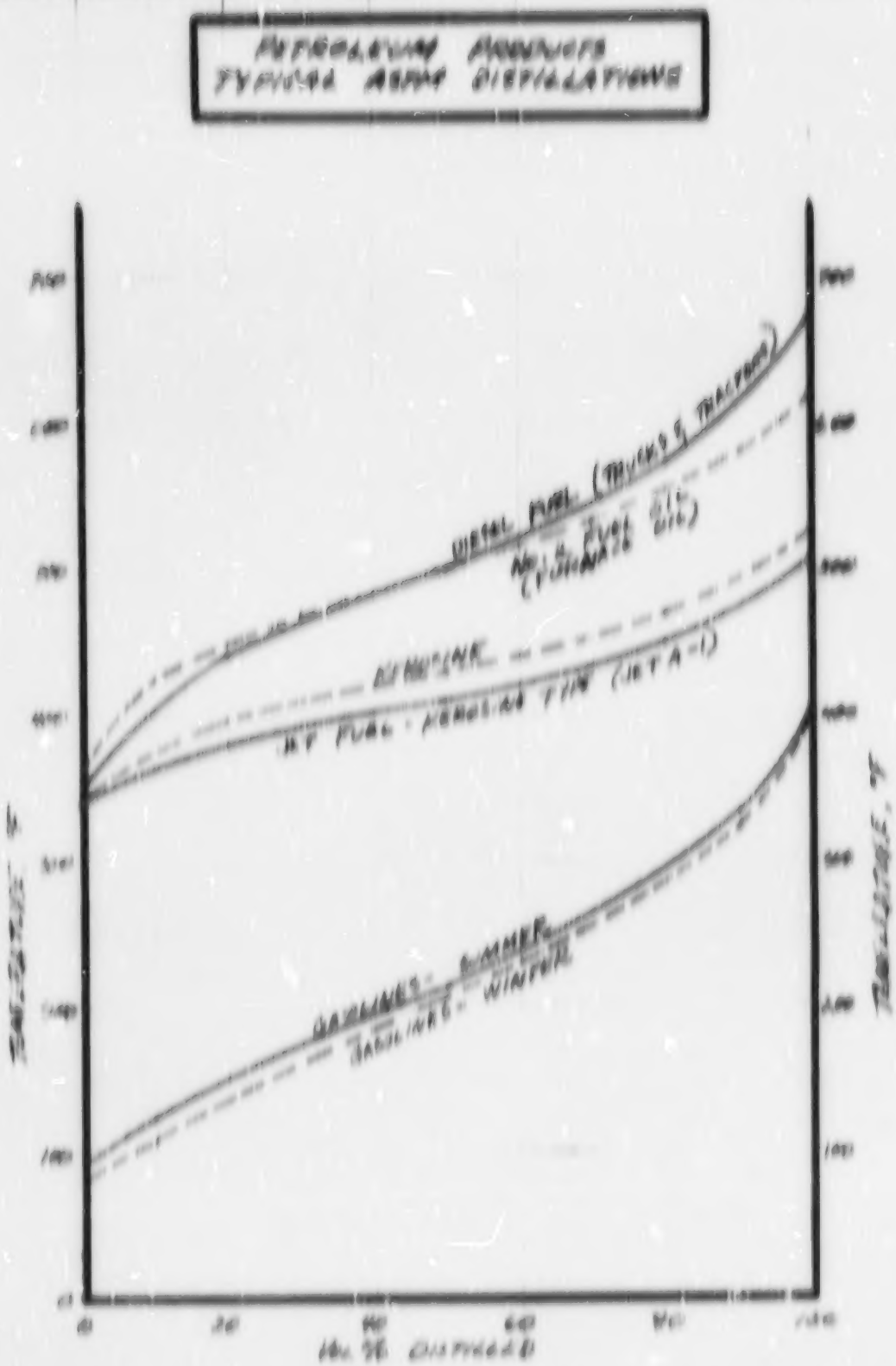


FIGURE 2



B. Case Studies of Refinery Yields

For these comparative studies on the potential production of automotive Diesel fuels, a refinery situation and crude oil feedstock was selected which yields about the same distribution of total gasolines, mid-distillates and residual fuel oil as the percent distribution of these products of the 1971 U.S. demand. Then by changing the operation of the refinery or adding new units, the potential yield of automotive Diesel fuel was estimated in comparison to Case 1 (base case).

The feedstock was considered to be 100,000 barrels per stream day (BPSD) of 32 °API south Louisiana crude for all cases. With 100,000 BPSD crude, the refinery yields in percent is simply the BPSD yield of each final product stream divided by 1,000 BPSD.

The cases considered are as follows:

Case 1. "A" Refinery which yields about the same distribution of total gasolines, mid-distillates, and No. 6 fuel as the 1971 U.S. demand. Conversion of gas oil in the fluid catalytic cracking unit was assumed to be 75%.

Case 2. "A" Refinery as in Case 1 except the catalytic cracking yields are at 65% conversion and increased recycle to increase the production of mid-distillates.

Case 3. "B" Refinery with a hydrocracker for increased production of mid-distillates.

Case 4. "C" Refinery with a hydrocracker and delayed coker for the potential maximum production of mid-distillates.

Thus Case 1 represents a refining situation which satisfies the U.S. demand for products; Case 2 represents the potential production of mid-distillates with little or no change in present refinery units; Case 3 represents the substitution of a hydrocracker in place of the cat cracker to further increase the production of mid-distillates; and Case 4 represents the potential maximum production of mid-distillates by eliminating production of residual fuel oil.

The term "mid-distillates" in this study refers to the distillates boiling between 350° to 600°F true boiling cut points and comprise the kerosine, aviation jet fuel, automotive Diesel fuels, and No. 2 fuel oil. Kerosine, aviation jet fuel and No. 1-D Diesel fuel are produced from the 350° to 500°F fractions. No. 2-D Diesel fuel and No. 2 fuel oil are blends of essentially 50% of the 350° to 500°F fractions with 50% of the 500° to 600°F fractions.

Case 1. "A" Refinery for Gasoline Production

Process facilities in Case 1 feature crude and vacuum distillation, naphtha reformer with platinum catalyst, fluid catalytic cracker at 75% conversion, vapor recovery, and alkylation.

Figure 3 shows the major process flows, product rates, and product properties based on 105,000 BPSD of 33 °API south Louisiana crude. The purchased isobutane for alkylation plus normal butane for gasoline vapor pressure amounts to 6.8 vol % on crude charge. Product yields are as follows:

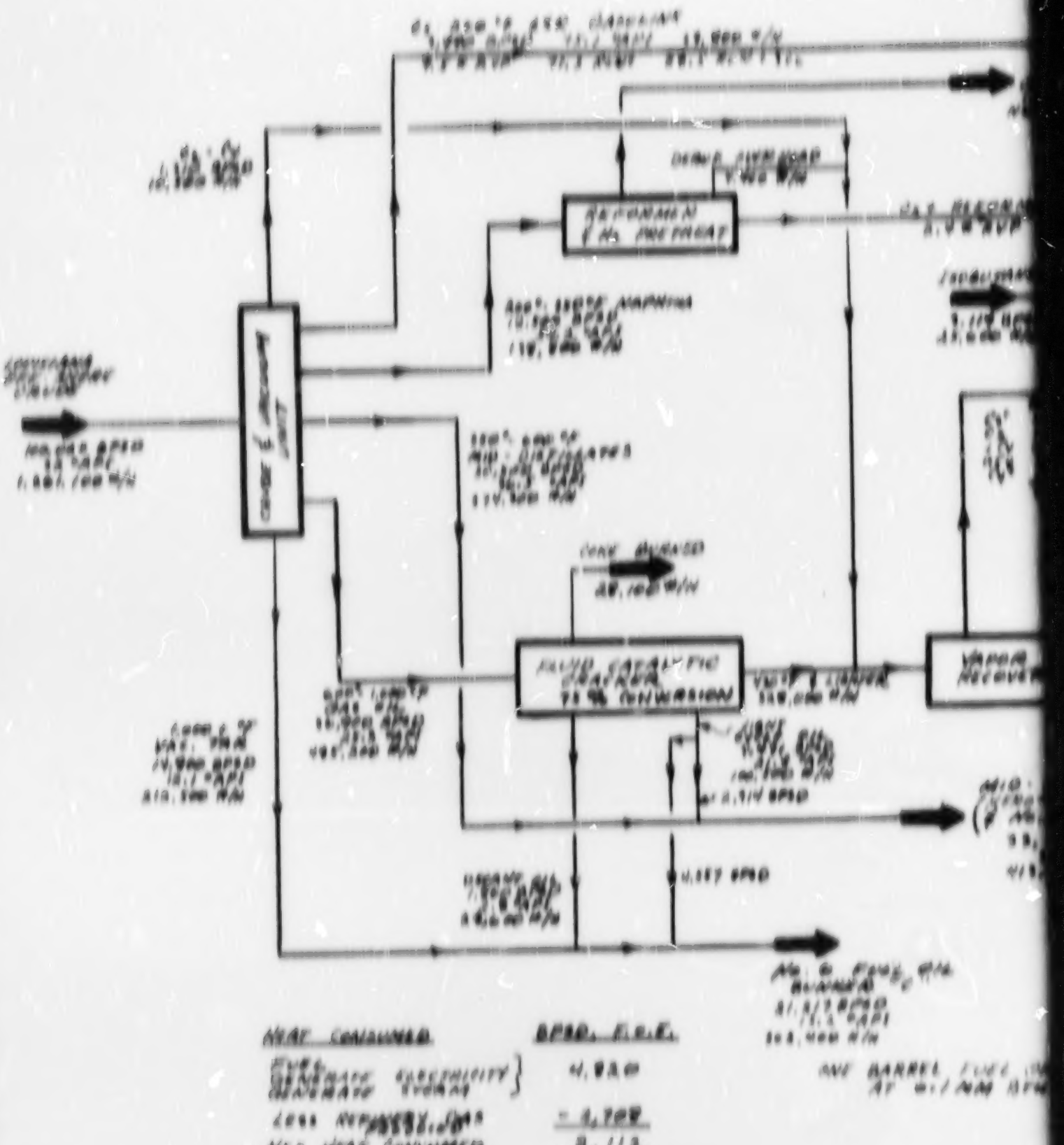
	BPSD	Distribution, %
Total Gasolines	50,578	48.1
Mid-Distillates	33,414	31.8
No. 6 Fuel Oil	21,217	20.1
	105,209	100.0

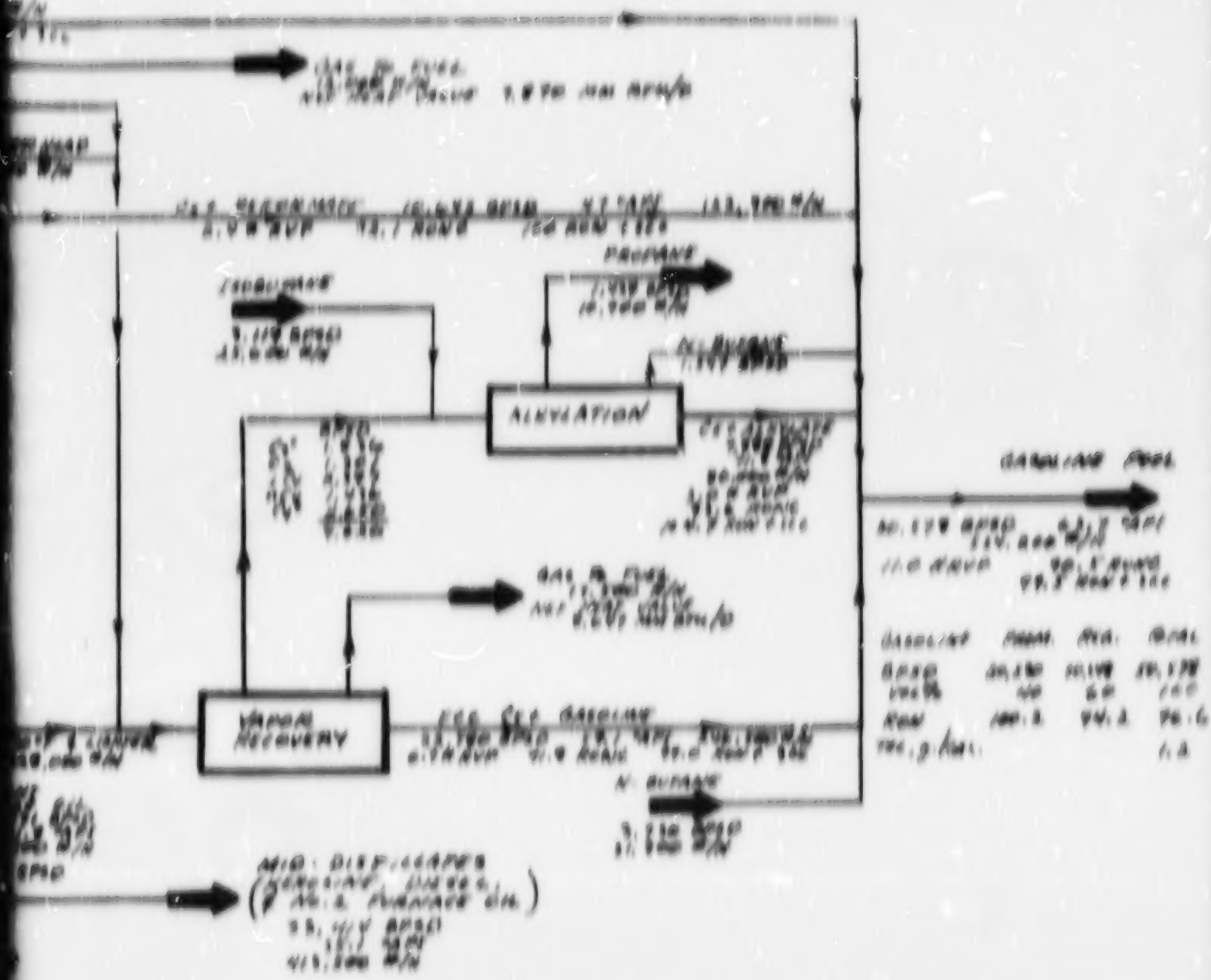
This distribution of products compares with the U.S. demand as follows:

	Distribution, %	
	Case 1	1971 U.S. Demand
Total Gasolines	48.1	50.4
Mid-Distillates	31.8	30.9
Residual Fuel Oil	20.1	18.7
	100.0	100.0

Octanes of the total gasolines are better than the present total U.S. gasoline sales which average 97.7 research octane at 3.5 grams lead alkyl per gallon. The higher octane is the result of no thermal cracking and alkylation of all of the propylene and butenes.

The total heat consumed as refinery fuel, to generate steam, and electrical generation equivalent is also shown in Figure 3. The net heat consumed amounts to 2.5 vol % on crude.





THE M. W. KELLOGG COMPANY
CASE I
"A" REFINERY
GASOLINE PRODUCTION
		FIGURE 3

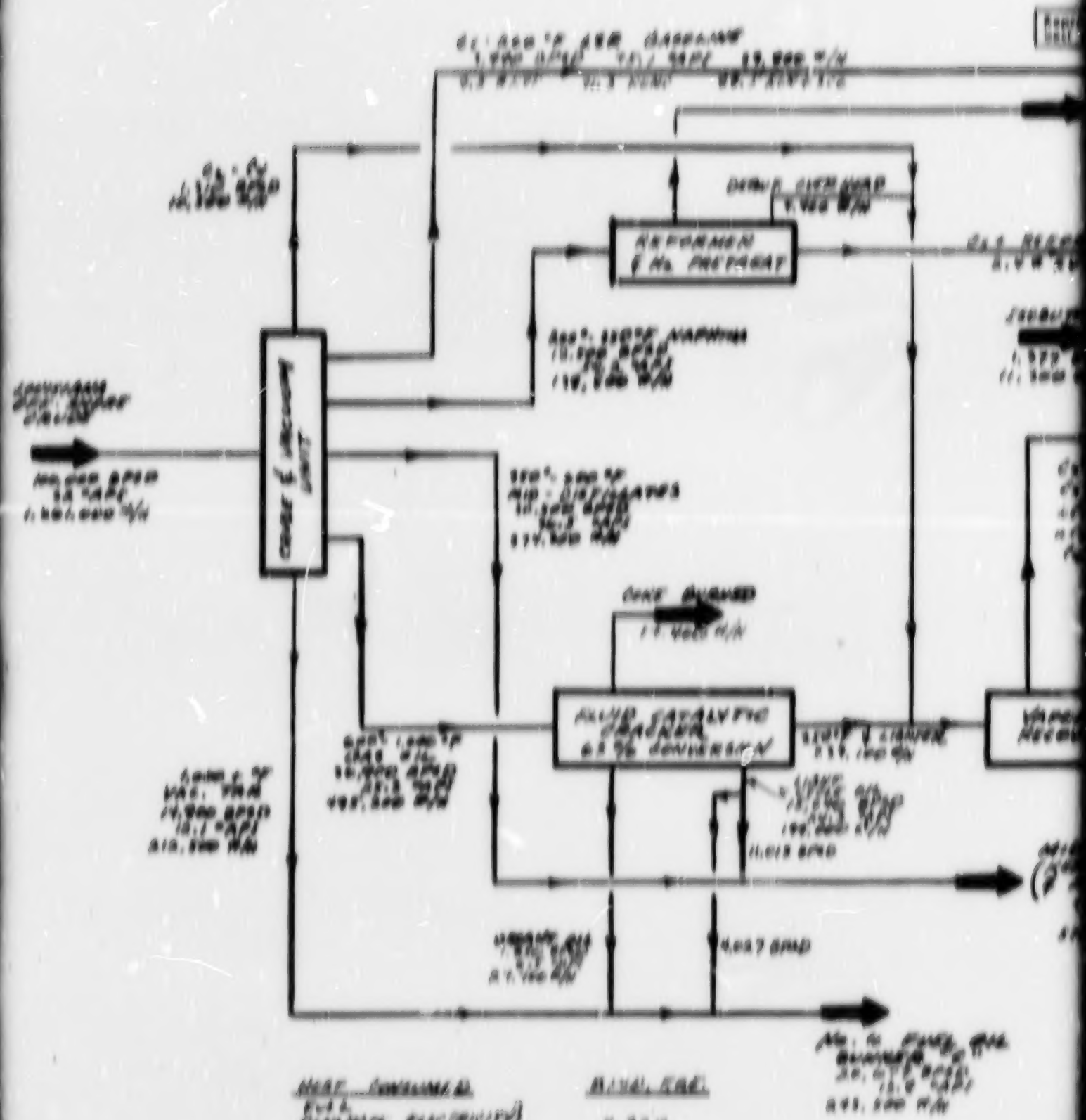
Case 3. "A" Refinery for Mid-Distillate Production

Process facilities in Case 3 are the same as in Case 1. The yields for catalytic cracking are based on 63% conversion and increased recycle to produce maximum light cycle oil. Since the majority of catalytic units were designed prior to the development of the mol sieve cat cracking catalysts, these units have the capacity for recycle with little or no revamp.

Figure 4 shows the major process flows, product rates, and product properties based on 100,000 BPSD of 32 °API south Louisiana crude. The purchased isobutane for alkylation plus normal butane for gasoline vapor pressure amounts to 3.8 vol % on crude charge. Products yields are as follows:

	BPSD	Distribution %
Total Gasolines	40,765	39.6
Mid-Distillates	41,513	40.3
No. 6 Fuel Oil	20,677	20.1
	102,955	100.0

The net heat consumed in the refinery amounts to 2.1 vol % on crude charge.



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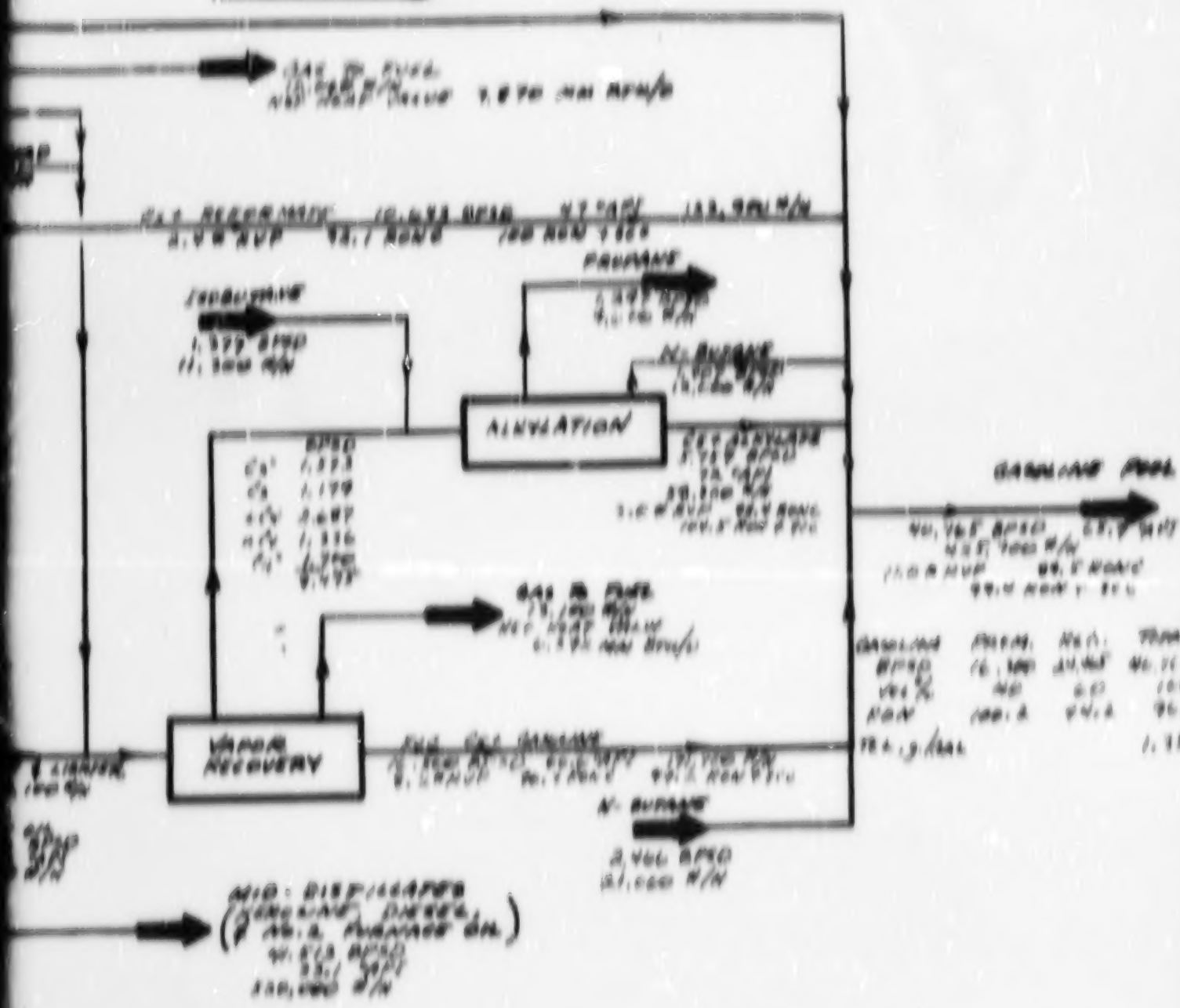


THE M. W. KELLOGG COMPANY A DIVISION OF PULLMAN INCORPORATED		
CASE B		
"A" REFINERY		
MID-DISTILLATE PRODUCTION		
	JOB	FIGURE #

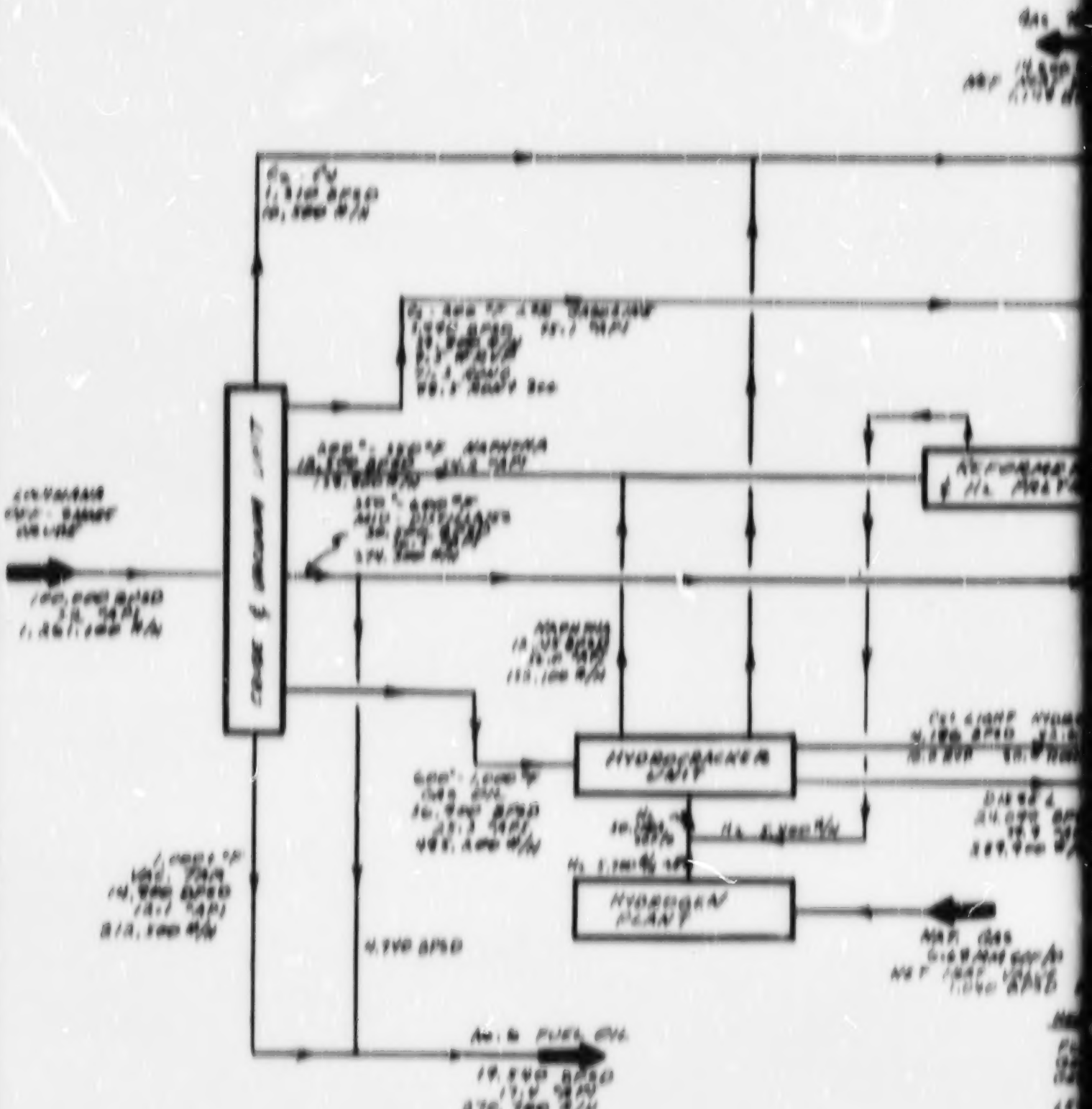
Case 3. "B" Refinery with Hydrocracker to Increase Mid-Distillates

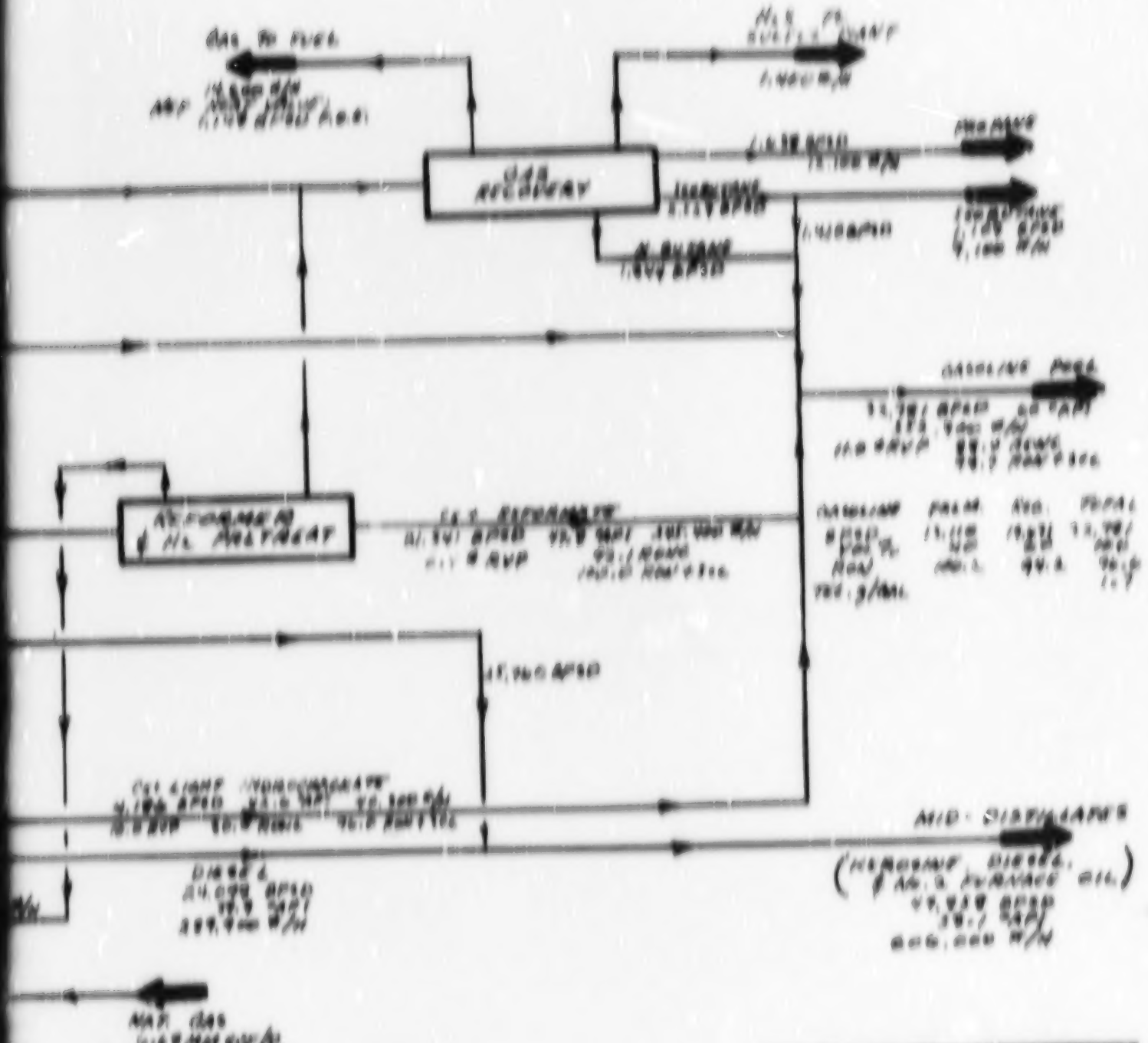
The production of Diesel fuel can be increased by hydrocracking the 600° to 1,000°F virgin gas oil. Process facilities in Case 3 feature crude and vacuum distillation, hydrogen plant, hydrocracker, reformer with capacity for virgin and hydrocracker naphthas, and saturate gas recovery.

Figure 5 shows the major process flows, product rates, and product properties based on 100,000 BPSD of 32 °API south Louisiana crude. Natural gas for the production of hydrogen would amount to 1,040 BPSD fuel oil equivalent (F.O.E.) net heat value. Product yields are as follows:

	BPSD	Distribution, %
Total Gasolines	32,781	32.1
Mid-Distillates	49,858	48.8
No. 6 Fuel Oil	19,540	19.1
	102,179	100.0

The net heat consumed in this refinery amounts to 6.4 vol % on crude charge.





HEAT CONSUMED	BTU/BBL
FUEL (GASOLINE, KEROSENE, GAS OIL, LOSS, RECOVERED GAS, PRODUCED GAS)	1,193
NET HEAT CONSUMED	+ 1,148 = 41,345

THE M. W. KELLOGG COMPANY
CASE 3
"B" REFINERY
WITH HYDROGENATION
JOB 4091-17 FIGURE 3

Rev. 11

Case 4. "C" Refinery with Hydrocracker and Delayed Coker

The production of automotive Diesel fuel can be further increased at the expense of decreased residual fuel yields. The virgin vacuum tar can be further processed by visbreaking, delayed coking, fluid coking, hydrocracking, catalytic cracking, or solvent deasphalting to yield gas, gasoline, mid-distillates, and residual fuel oil or coke. In addition to the increased yields of mid-distillates, the mid-distillate required to blend with the tar to meet the viscosity specification for residual fuel would be reduced or not be required.

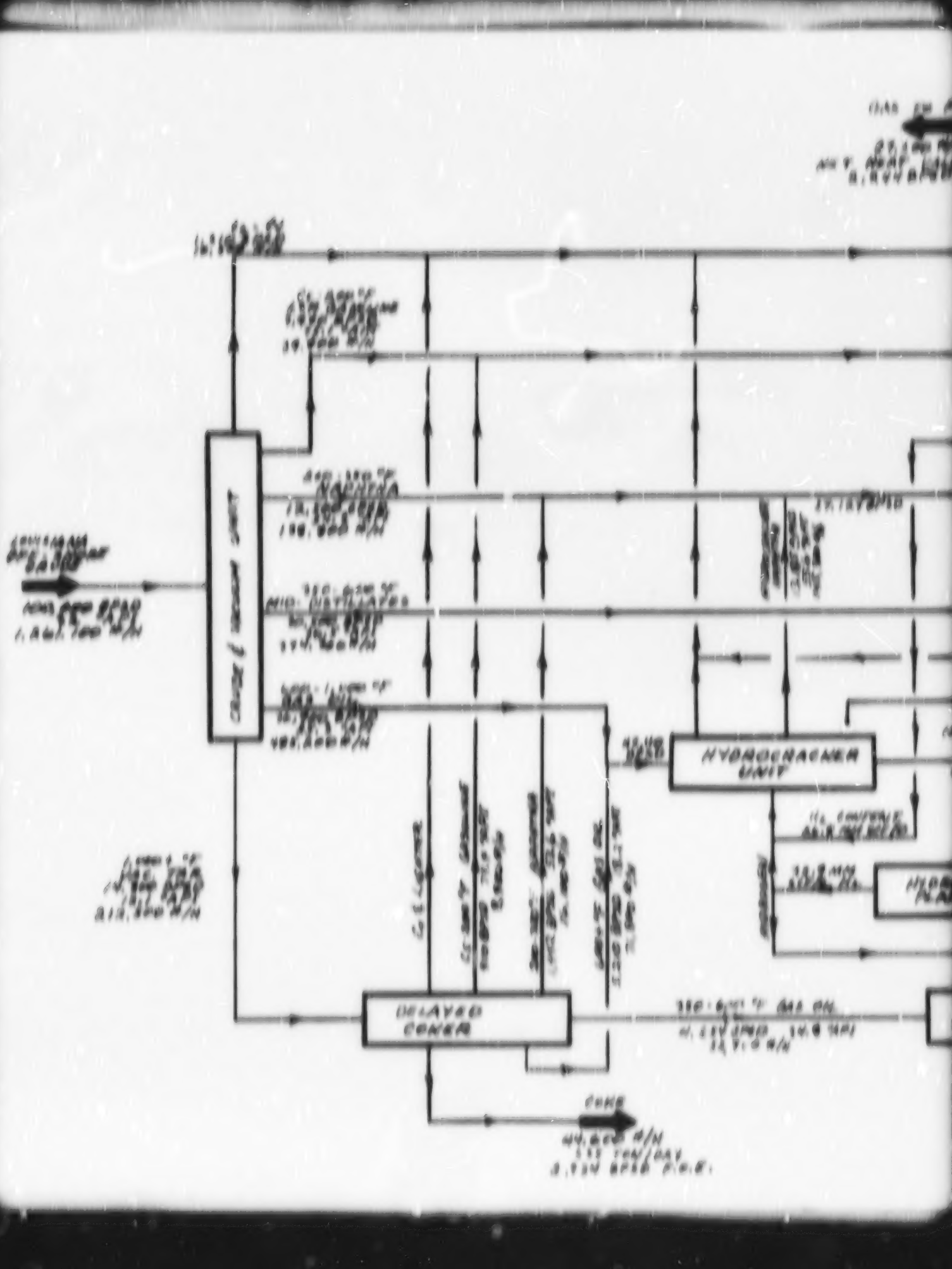
The potential maximum production of Diesel fuel can be realized by delayed coking of the vacuum tar. In Case 4, the process facilities feature delayed coking of the 1000 + °F vacuum tar; hydrotreating the coker 350° to 600°F gas oil; hydrocracking the 600° to 1,000°F virgin gas oil and the 600 + °F coker gas oil; and reforming the 200° to 350°F naphthas from the crude unit, delayed coker, and hydrocracker.

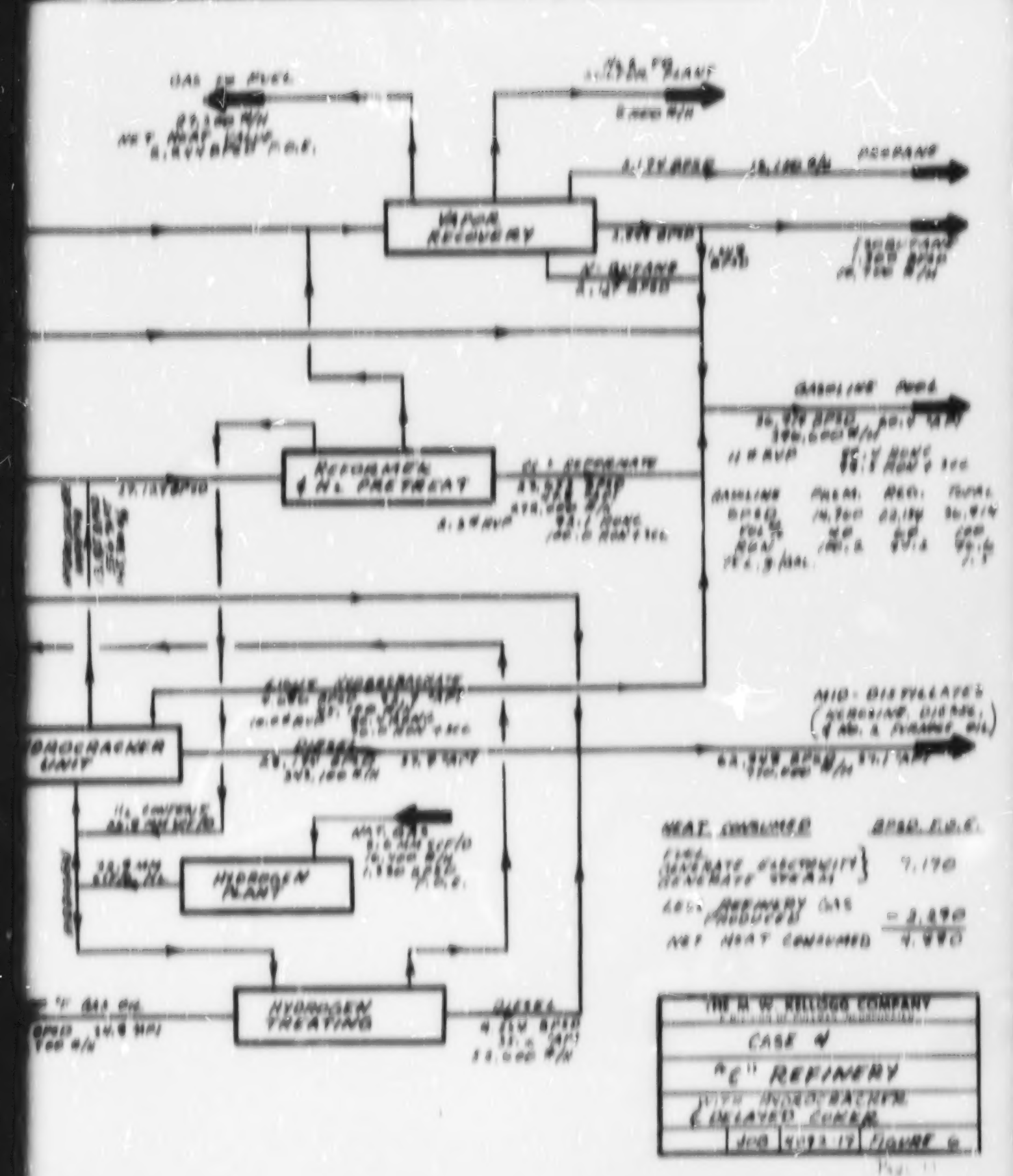
Figure 6 shows the major process flows, product rates, and product properties based on 100,000 BPSD of 32 °API south Louisiana crude. Natural gas for the production of hydrogen amounts to 1,330 BPSD fuel oil equivalent net heat value. Product yields are as follows:

	BPSD	Distribution, %
Total Gasolines	36,911	37.0
Mid-Distillates	62,948	63.0
Residual Fuel Oil	None	
	99,859	100.0

The delayed coker produces 535 tons per day of coke. This is equivalent in net heat value to 3,934 BPSD fuel oil (3.9 vol % on crude charge).

The net heat consumed in this refinery amounts to 4.8 vol % on crude charge.


HYDROCRACKER UNIT
DELAYED COKER
COKE


VAPOR RECOVERY
HYDROGEN PLANT
HYDROGEN TREATING
HEAT CONSUMED
BTU/U.S. GAL.
NET HEAT CONSUMED
THE M. W. KELLOGG COMPANY
CASE 4
"C" REFINERY
WITH HYDROTREATING
& UNLEADED GASOLINE

f. Comparison of Cases

The distribution of products for the 1971 U.S. demand is compared with the distribution from these Cases as follows:

	Distribution, %			
	Total Gasolines	Mid-Distillates	Residual Fuel	Total
1971 U.S. Demand	50.4	30.9	18.7	100.0
Case 1	48.1	31.8	20.1	100.0
Case 2	39.6	40.3	20.1	100.0
Case 3	32.1	48.8	19.1	100.0
Case 4	37.0	63.0	None	100.0

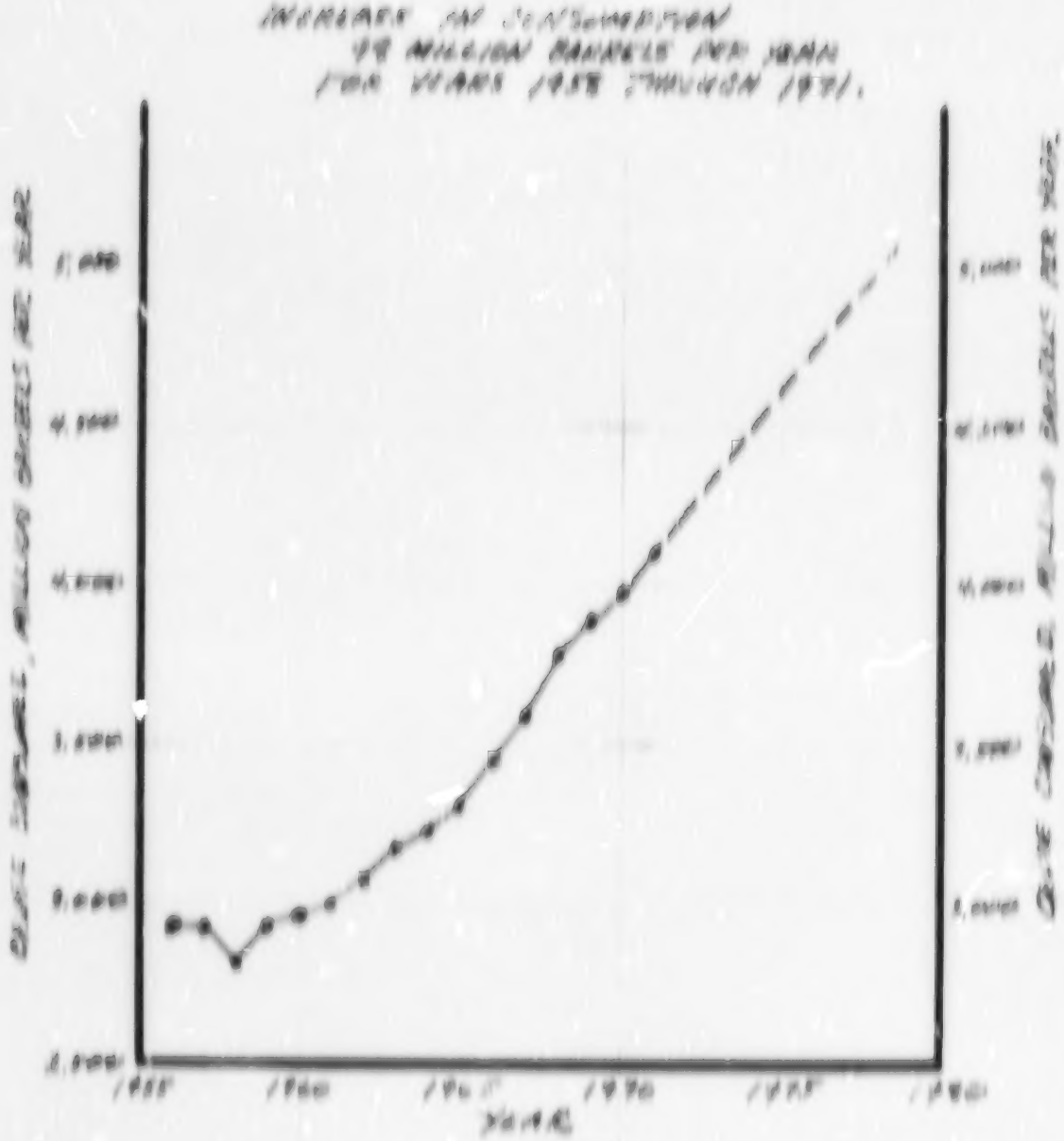
The annual consumption of crude oil in the United States is shown in Figure 7. In 1971, the crude runs in U.S. refineries were 4,088 million barrels. Based on Figure 7 it is projected that the consumption of crude oil will be 5,000 million barrels per year by 1978.

If the yields for Cases 1, 2, 3, and 4 are based on an annual crude run of 5,000 million barrels per year, the yields of products would be as follows:

	Annual Production, Million Barrels			
	Total Gasolines	Mid-Distillates	Residual Fuel	Total
Case 1	2,530	1,670	1,060	5,260
Case 2	2,040	2,080	1,030	5,150
Case 3	1,640	2,490	980	5,110
Case 4	1,850	3,150	None	5,000

FIGURE 7.

ANNUAL CONSUMPTION OF CRUDE OIL IN UNITED STATES



D Potential Production of Automotive Diesel Fuel

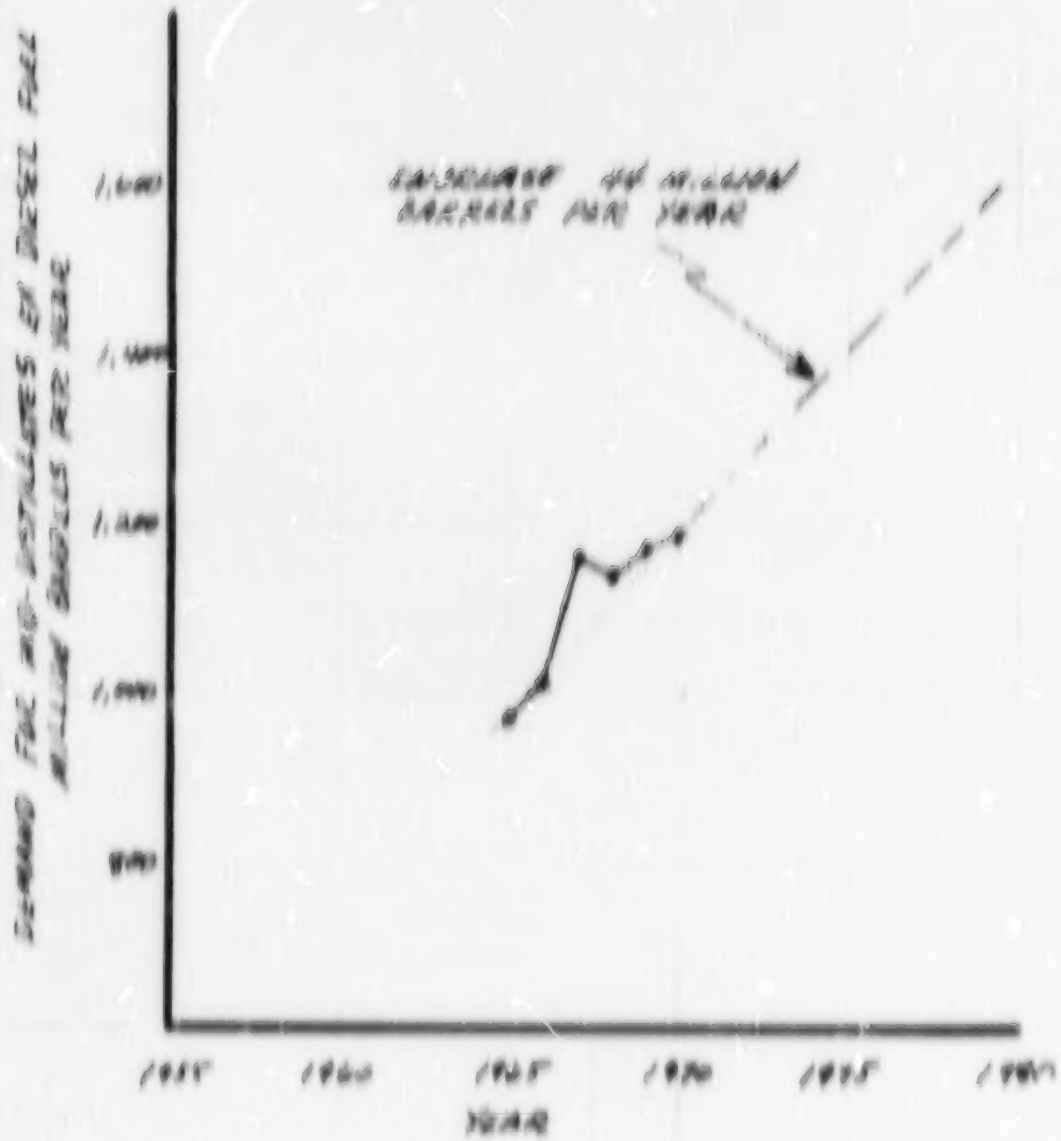
The U.S. demands for mid-distillates as automotive Diesel fuels are shown in Figure 8. In 1978, the projected demand would be 1,540 million barrels per year.

Automotive Diesel fuels may be estimated to be the difference between the total production of mid-distillates and the projected demand of 1,540 million barrels. Still based on 5,000 million barrels per year of crude oil consumption per year, the production of automotive Diesel fuel would be as follows in 1978:

	Annual Production of Automotive Diesel Fuel, Million Barrels	
		Above Case 1
Case 1	130	Base
Case 2	540	+ 410
Case 3	950	+ 820
Case 4	1,610	+1,480

FIGURE 3.

U. S. DEMAND FOR
MID - DISTILLATES
EX AUTOMOTIVE DIESEL FUELS

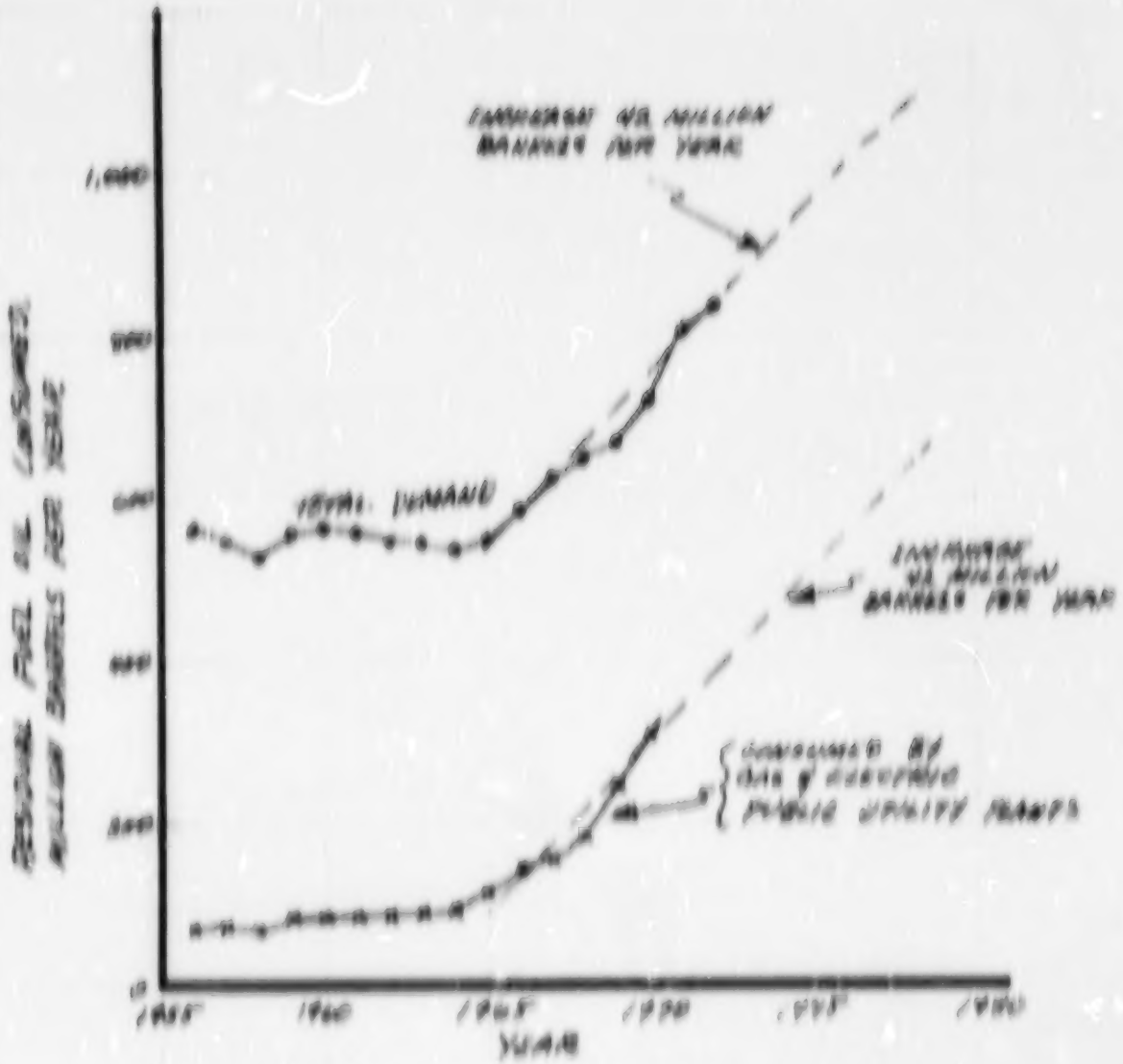


E. Consumption of Residual Fuels in United States

In Cases 1, 2, and 3, the production of residual fuel oil was considered to be 18 .0% of the total gasoline, mid-distillates, and residual fuel oil. The annual consumption of residual fuel oils in the United States is shown in Figure 9. This graph indicates that the consumption of residual fuel is increasing at the rate of 42 million barrels per year, and the increase can be attributed generally to the increased consumption by electric public utility plants.

FIGURE 9.

ANNUAL CONSUMPTION
OF RESIDUAL FUELS
IN UNITED STATES



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Associated Octel Company, Limited—London

"World Wide Survey of Motor Gasoline Quality" May, 1971.

"Petroleum Processing Handbook" Section 11, Petroleum Products by V. B. Guthrie.

TABLE I

U. S. Demand for Petroleum Products in 1971

	Million Barrels in 1971	%
Total Gasolines	2,262*	50.4
Kerosine	91	
Jet Fuel–Kerosine Type	319*	
Distillate Fuel Oil	974	
Mid-Distillates	1,384	30.9
Residual Fuel Oil	838	18.7
Total Above Products	4,484	100.0

*Jet Fuel – Naphtha Type demand of 95 million barrels divided 50% to gasolines and 50% to Jet Fuel–Kerosine Type.

TABLE II
U.S. Production of Petroleum Products in 1971

	Million Barrels in 1971	% Yield
Gasoline*	1,949	47.2
Kerosine	86	2.1
Jet Fuel–Kerosine Type*	262	6.4
Distillate Fuel Oil	910	22.0
Residual Fuel Oil	276	6.6
Lubricants	65	1.6
Others	583	14.1
	4,131	100.0

*Jet Fuel–Naphtha Type divided 50% to gasolines and 50% to Jet Fuel–Kerosine Type.

TABLE II A
Production of Miscellaneous Petroleum Products

	Year	Petroleum Equivalent, Million Barrels per Year	Notes
Asphalt	1963	124	(1)
Petroleum Coke	1962	32	(2)
Petrochemicals	1964	263	(3)
Carbon Black (Furnace)	1963	5	(4)
Petroleum Waxes	1964	5	(5)
		428	

Notes:

(1) Converted from short tons at 5.5 barrels per ton.

(2) Converted from short tons at 5 barrels per ton.

(3) Converted from pounds at 305 pounds per barrel.

(4) Converted from pounds at 350 pounds per barrel.

(5) Converted from pounds at 300 pounds per barrel.

TABLE III
U.S. Demand for Mid-Distillates by Use in 1970

	Million Barrels in 1970	%
Jet Fuel–Naphtha Type	45	3.4
Kerosine	96	7.2
Jet Fuel–Kerosine Type	262	19.7
No. 1 Range Oil	15	1.1
Heating Oils	510	38.4
Industrial Uses	45	3.4
Oil Company Fuel	12	0.9
Gas and Electric Company Public Utility Power Plants	25	1.9
Railroads	88	6.6
Vessel Bunkering Including Tankers	20	1.5
Military Uses	12	0.9
Diesel Fuel Used on Highways	149	11.2
Miscellaneous and Unaccounted	51	3.8
	1,330	100.0

TABLE IV

U.S. Demand for Residual Fuels by Uses in 1970

	Million Barrels	%
Heating Oils	186	23
Industrial Uses	138	17
Oil Company Fuel	39	5
Gas and Electric Public Utility Power Plants	309	38
Railroads	3	-
Vessel Bunkering Including Tankers	87	11
Military Uses	38	4
Miscellaneous and Unaccounted	15	2
	804	100

TABLE V

Production and Uses of Crude Oil in U.S. in 1971

Production of Crude Oil	Million Barrels	%
Crude Oil and Lease Condensates	3,478	85
Imports	613	15
	4,091	100

Uses of Crude Oil	Million Barrels	%
Refinery Runs	4,088	99.75
Transferred to Fuel Oil	6	0.15
Losses	4	0.10
	4,098	100.00

TABLE VI
Natural Gas Liquids and Liquefied Refinery Gases -
U.S. Total Supply and Demand by Use: in 1971

Production	Million Barrels	%
Plants	618	78.5
Refineries	130	16.5
Imports	39	5.0
	787	100.0

Demand by Use	Million Barrels	%
Exports	9	1.2
Blended at Refineries	285	37.5
Other Blends and Transfers	9	1.2
L.P. Gas Sales	457	60.1
	760	100.0

TABLE VII
U.S. Refinery Input in 1971

Refinery Input	Million Barrels	Vol % on Crude
Crude Oil (Refinery Runs)	4,088	100
L.P.G. and Natural Gas Liquids Blended at Refineries	285	7
	4,373	107